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The impacts of renewable energy and technological innovation on environment-energy-growth nexus: New evidence from a panel quantile regression

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ABSTRACT

To mitigate climate change, many studies have been conducted to identify the determinants of CO_2 emissions. However, a consensus has not been reached yet on the issue because past work has often not considered the unobserved individual heterogeneity across countries. Therefore, this study revisits the environment-energy-growth nexus by employing a panel quantile regression to incorporate the effects of renewable energy consumption and technological innovation within the research background of global 30 countries over the period 1980–2014. The advantage of this method is considering the distributional heterogeneity to provide a detailed description of linkage between the CO_2 emissions and driving factors at different emissions levels. The results show that the effects of determinants on CO_2 emissions are heterogeneous. For high-emissions countries, the function of renewable energy consumption is limited in reducing CO_2 emissions due to the smaller proportion of renewable energy use. Moreover, technological innovation greatly affects countries with relatively higher CO_2 emissions. Therefore, one option is to financially support and apply technological innovations to generate renewable energy at lower costs as well as increase energy efficiency. Moreover, transforming the economic growth mode is helpful to transfer from non-renewable to renewable sources of energy to meet energy demand.
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1. Introduction

With rapid economic development and technological progress, the demand for energy in developed and developing countries has increased. Although energy consumption can lead to economic growth, it is the principal reason for environmental degradation [1]. Over the past few decade, environmental pollution has become one of the greatest global issues because of large increases in greenhouse gas (GHG) emissions [2]. With the development of industry, GHG emissions, carbon dioxide (CO_2) emissions in particular, have sharply increased [3]. Moreover, the IPCC (2007) predicted that energy-related CO_2 emissions in 2030 will have increased by 40–110%. Therefore, it is necessary to investigate the energy consumption-related factors that influence changes in CO_2 emissions to realize energy-saving emission reduction and achieve low carbon economy development.

Regarding the main factors driving CO_2 emissions, the majority of studies have focused on economic growth and aggregate energy consumption. However, according to [4] and [5], aggregate energy consumption and economic growth alone may fail to explain changes in CO_2 emissions. In fact, in order to attain sustainable economic development, countries have turned their attention to the development and utilization of renewable energy. We will rely on renewable energy in the future [6]. In 2014, renewable energy accounted for 19.2% of global final energy consumption. The International Energy Agency (IEA) predicted that renewable energy will be the fastest growing component of global energy demand. For example, renewable energy technologies are the fastest growing sources of electricity in the US. Furthermore, environmentalist [7,8] have increased interest in the distribution of renewable energy resources in the power system because renewable energy is a virtually carbon-free energy source that can serve as a potential solution to climate change problems. However, according to [9], a much smaller part of work in the literature

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Nomenclature

Abbreviation

CO_2	Total carbon dioxide emissions
NRE	Non-renewable energy consumption
RE	Renewable energy consumption
PGDP	Real per capita gross domestic product
TECH	Technological innovation
FDI	Foreign direct investment
NRE	International Energy Agency
FINA	Financial development
POP	Population size

Symbols

L	Natural logarithms

investigated the linkage between economic growth and energy consumption by energy source (i.e., renewable energy consumption and non-renewable energy consumption). Therefore, we need to pay attention to the impact of renewable energy consumption on CO_2 emissions.

Because technological innovation is crucial in improving energy efficiency [10–12], it is a factor worthy of our attention when we explore the determinants of CO_2 emissions. High technology enables the economy to produce a level of output consuming a lower level of energy [13]. Moreover, technological innovation could lead to quicker adoption of renewable energy to meet energy demands and change the energy consumption structure. Even though previous researchers have extensively analyzed the relationship between disaggregated energy consumption, CO_2 emissions and economic growth, they did not include the effect of technological innovation in the environment-energy-growth nexus. Therefore, this paper discusses the influence of technological innovation on CO_2 emissions to expand the research target.

In terms of research method, most of the existing literature [14–19] adopted conventional panel estimation techniques that failed to consider unobserved individual and distributional heterogeneities across countries in the panel. In addition, some studies rely on a multivariate framework without including some control variables which lead to the omitted variables bias.[1] As a result, existing studies did not come to the consensus conclusion concerning the effects of driving factors on CO_2 emissions. To fill these gaps, we examine the determinants of CO_2 emissions using panel quantile regression, adding relevant variables as control variables.

This paper makes several contributions to the existing literature. First, as shown in Table 1 in the appendix section, most existing studies used aggregate energy consumption as variable in their models and thus failed to estimate the effects of energy consumption by source. Instead, we include renewable and non-renewable energy sources separately in this models, and as such, it provides us some new finding about their disaggregated impacts on CO_2 emissions. Second, it employs the panel quantile regression method to empirically investigate the influence of driving factors on CO_2 emissions at different levels of CO_2 emissions in global 30 countries, which could provide more complete results compared to conventional panel regression and demonstrate the possible heterogeneity. Third, in order to avoid the omitted-variable bias faced by previous studies, several related control variables are included in our model. Indeed, against the background of an apparent lack of consensus in the literature on the environment-energy-growth nexus issue, the results of this study could provide scientific information for policy-makers to target policies to meet the CO_2 emissions level of a specific country rather than on the average of the entire group.

The outline of this paper is organized as follows: Section 2 reviews the related literature on the environment-energy-growth issues. Section 3 explores the panel quantile regression model and data, and Section 4 presents the results and a detailed discussion. The last section concludes the paper and presents related policy implications.

2. Literature review

There are three main research groups studying the environment-energy-growth nexus in the environmental economics literature. First, scholars ([20–24]) focuses on examining the validity of the Environmental Kuznets Curve (EKC) hypothesis. In fact, in the most EKC framework, one limitation of this group is that they identified the relation between environment and income in a bivariate framework and hence suffers from omitted variable bias [25–29]. Therefore, in order to circumvent omitted variable bias in EKC framework [30–32], introduced energy consumption into the link between CO_2 emissions and economic growth (Appendix Table 1) and found that the environmental EKC hypothesis was invalid. Some scholars [25,33–36] confirmed the existence of U-shaped relationship between CO_2 emissions and economic growth by building on the environmental Kuznets curve (EKC) framework. While there was also some evidence that the EKC hypothesis was an N-shaped relationship [37]. Indeed, existing studies also failed to find evidence of a consensus conclusion about the effects of economic growth on CO_2 emissions.

Actually, the influence of energy consumption in CO_2 emissions is also controversial. Some scholars concluded that total energy consumption has a positive effect on CO_2 emissions [25,32,38–40]. Some researchers [25,32] thought that there existed bidirectional causality between CO_2 emissions and economic growth. While, according to [39,41], there was unidirectional causality from energy consumption to CO_2 emissions. Some results of Granger causality tests indicated the existence of a positive causality from CO_2 emissions to energy consumption [6].

Second, the majority of the environment-energy-growth nexus comes from aggregate energy consumption and conventional fossil energy consumption. Indeed, a much smaller body of work in the literature discussed the relationships between non-renewable energy consumption, renewable energy use, economic growth and CO_2 emissions (Appendix Table 2). All previous studies showed that the non-renewable energy consumption stimulates the CO_2 emissions, but the findings varied regarding the effects of renewable energy consumption.

Renewable energy consumption has contributed to CO_2 emissions reduction and improvement in technical and economic efficiency [42] [43].concluded the unidirectional causality exists between renewable energy use and economic growth. While, some researchers [44,45] revealed a bidirectional causality between them. And, some scholars [18,23,24,46–48] found that renewable energy mitigated CO_2 emissions. While [15,49,50], supported the renewable energy consumption has positive effect on CO_2 emissions. In addition [51], thought that GDP and renewable energy consumption contributed to CO_2 for lower threshold, while renewable energy use mitigated CO_2 for upper threshold. In conclude, empirical findings regarding the nexus of economic

[1] Omitted variables bias occurs when some variables are correlated with the dependent variable and one or more other independent variables but they are omitted in a regression model.

Table 1
Variable definitions and data sources.

Variable	Definition	Units	Source
CO_2	Total CO_2 emissions from the consumption of energy	Thousand metric ton	EIA
NRE	Total primary energy (coal, oil and gas) consumption	Thousand tonnes oil equivalent	BP-statistical review
RE	Total renewable energy consumption	Thousand tonnes oil equivalent	BP-statistical review
TECH	Total patent applications	people	Database of the World Bank
PGDP	real per capita GDP	constant 2010 US$	Database of the World Bank
FINA	Financial development, domestic credit to private sector (% of GDP)	Percent	Database of the World Bank
TR	Trade (% of GDP)	Percent	Database of the World Bank
FDI	Foreign direct investment, net inflows (% of GDP)	Percent	Database of the World Bank
POP	Population size	people	Database of the World Bank

Table 2
The classification of selected countries.

Continents	Number	Country Name
Europe & Central Asia	13	Netherlands (NLD),Norway (NOR),Finland (FIN),Germany (DEU),Greece (GRC), Ireland (IRL),Denmark (DNK),Portugal (PRT),Spain (ESP),Sweden (SWE) Turkey (TUR),France (FRA), United Kingdom (GBR)
South Asia	2	Bangladesh (BGD),India (IND)
North America	2	Canada (CAN), United States (USA)
Latin America & Caribbean	3	Chile (CHL),Mexico (MEX),Peru (PER)
East Asia & Pacific	6	China (CHN),Indonesia (IDN),Japan (JPN), New Zealand (NZL) Philippines (PHL),Thailand (THA)
Middle East & North Africa	3	Iran, Islamic Rep.(IRN),Egypt (EGY),Israel (ISR)
Sub-Saharan Africa	1	South Africa (ZAF)

growth, energy consumption and CO_2 emissions are mixed. Overall, the majority of previous researchers reported incongruent empirical findings towards this puzzled relationship.

Studies in the third strand address the importance of technological innovation on this issue (Appendix Table 3) [52].concluded a unidirectional causality from technological innovation to renewable energy use. Besides [53], also obtained that technological innovation is significant in decreasing the use of fossil fuels based on ARDL approach. Some scholars [16,45] found that research and development (R&D) expenditures has positive influence in economic growth. Investments in R&D and change in technology could reduce the CO_2 emissions [54]. Therefore, technological innovation played a major role in reducing energy consumption and improving energy efficiency [13].

In conclude, it has not yet recognized a consensus conclusion on this environment-energy-growth issue. Some reasons may explain the different conclusions reached in previous works: The samples used for research are different; the models and methods adopted to study relationships vary; and the control variables included in the model are diverse [55,56] [57]. argued that the shortcoming of previous studies was that the results suffered from deviation due to a neglect of distributional heterogeneity. In addition, because of the only two or three control variables in previous studies, there was m omitted-variable bias.

Therefore, this study revisits the environment-energy-growth nexus by employing a panel quantile regression to incorporate the effects of renewable energy consumption and technological innovation. The advantage of this method is that the distributional heterogeneity may be included to provide a detailed description of linkage between the CO_2 emissions and driving factors at different emissions levels. Besides, in order to eliminate the omitted-variable bias faced by previous studies, several related control variables are included in our model.

3. Methodology and data

3.1. Panel quantile regression model

In this study, a panel quantile regression model is built to investigate the impacts of economic growth, technological innovation, and renewable and non-renewable energy consumption on CO_2 emissions. Based on the results of Hausman tests, we employed a fixed effect model for regression. By adopting a fixed effect panel quantile regression method, we are able to depict the determinants of CO_2 emissions throughout the conditional distribution.

Quantile regression, which was proposed by Ref. [58], is helpful in investigating asymmetric features of variable distributions. This method can obtain the estimated coefficients across the different

Table 3
Summary of descriptive statistics.

Variable	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Probability
LCO_2	11.99463	16.06905	8.857537	1.488117	0.54761	2.670323	52.98187	0.0000
LNRE	11.1318	14.90477	8.023526	1.423147	0.546366	2.749299	50.9051	0.0000
LRE	8.139872	12.59104	−0.792857	2.054402	−0.966409	4.876657	293.9338	0.0000
LTECH	8.493805	13.74098	4.532599	1.833962	0.557294	3.230372	52.46277	0.0000
LPGDP	9.361507	11.42512	5.863168	1.410646	−0.742941	2.436558	102.2751	0.0000
FINA	2.168107	32.30119	−28.62426	3.103832	1.223639	25.59758	20923.91	0.0000
TR	58.13706	209.6567	12.00868	28.41316	1.536372	6.978022	1023.29	0.0000
FDI	74.71746	221.2885	5.771342	48.43095	0.759819	2.835242	94.62593	0.0000
LPOP	12.96174	16.59913	10.2621	1.330705	0.63191	2.825279	65.92466	0.0000

Note: “L” means the variable in natural logarithms.

quantiles. The conditional quantile of y_i givenx_i, is as follows:

$$Q_{y_i}\left(\tau\middle|x_i\right) = x_i^T\beta_\tau \tag{1}$$

$$Q_{y_{it}}(\tau|\alpha_i,\xi_t,x_{it}) = \alpha_i + \xi_t + \beta_{1\tau}LNRE_{it} + \beta_{2\tau}LRE_{it} + \beta_{3\tau}LTECH_{it} + \beta_{4\tau}LPGDP_{it} + \\ +\beta_{5\tau}FINA_{it} + \beta_{6\tau}TR_{it} + \beta_{7\tau}FDI_{it} + \beta_{8\tau}LPOP \tag{5}$$

Quantile regression is robust to outliers and heavy distributions. However, these methods do not take into account the unobserved heterogeneity of a country [57]. Therefore, some scholars [59–64] studied the econometric theory of applying quantile regressions to panel data. In this paper, we employ a panel quantile method with fixed effects, which makes it possible to estimate the conditional heterogeneous covariance effects of carbon emissions drivers, thus controlling for unobserved individual heterogeneity. Consider the following fixed effect panel quantile regression model:

$$Q_{y_{it}}\left(\tau_k\middle|\alpha_i,x_{it}\right) = \alpha_i + x_{it}^T\beta(\tau_k),\ i = 1,\ldots,N; t = 1,\ldots,T \tag{2}$$

In formula (2), α_i have a pure location shift effect on the conditional quantiles of the response. The effects of the covariates $x_{it}$are permitted to depend upon the quantile τ of interest. i is the index of individual and t is the index of time. N is the number of observations on the individual i. T is the number of observations on the time t.

[59] treated unobservable fixed effect as parameters to be jointly estimated with the covariate effects for different quantiles. A unique characteristic of this method is the introduction of a penalty term in the minimization to address the computational problem of specifically estimating a mass of parameters; the parameter estimate is calculated as follows:

$$\min_{(\alpha,\beta)} \sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{i=1}^{N} w_k\rho_{\tau_k}\left(y_{it} - \alpha_i - x_{it}^T\beta(\tau_k)\right) + \lambda\sum_{i}^{N}|\alpha_i|,\ i \\ = 1,\ldots,N; t = 1,\ldots,T \tag{3}$$

Where K is the index of quantiles, x is the matrix of explanatory variables, $\rho_{\tau_k}$is the quantile loss function, and$w_k$is the relative weight given to the$k-th$quantile, which controls for the contribution of the $k-th$ quantile on the estimation of the fixed effect.

Furthermore, we estimate the effect of economic growth (PGDP), technological innovation (TECH), renewable energy consumption (RE) and non-renewable energy consumption (NRE) on CO_2 emissions by modifying the specifications of previous studies. In this paper, we employ equally weighted quantiles $w_k = 1/K$[65,66] and set $\lambda = 1$ [67]. We specify the conditional quantiles function for quantile τas follows

$$Q_{y_{it}}(\tau|\alpha_i,\xi_t,x_{it}) = \alpha_i + \xi_t + \beta_{1\tau}LNRE_{it} + \beta_{2\tau}LRE_{it} + \beta_{3\tau}LTECH_{it} \\ + \beta_{4\tau}LPGDP_{it} \tag{4}$$

Where the countries are indexed by i and time by$t$. y_{it} is the CO_2 emissions indicator.

This paper employs a panel quantile regression model that considers the unobserved individual and distributional heterogeneity. Moreover, to avoid an omitted-variable bias, based on previously published studies ([29,56,68–72]), population (POP), trade openness (TR), foreign direct investment (FDI), and financial development (FINA) are selected as control variables in the model (Equation (5)).

3.2. Data and descriptive statistic

3.2.1. Data source

In this paper, the dependent variable is CO_2 emissions, and the explanatory variables are the real per capita GDP (constant 2010 US$), technological innovation ([53,73] use patent data as a proxy for technological innovation), renewable energy consumption and non-renewable energy consumption (fossil fuel energy consumption). The data cover the period of 1980–2014 which was chosen due to the availability of the data. All variables are transformed with natural logarithms to help eliminate heteroscedasticity. In order to overcome omitted-variable bias, we consider relevant variables as control variables. According to previous researches ([29,56,68–72]), we choose trade openness, foreign direct investment, the population size, and financial development as control variables. The variables descriptions, data definitions and data sources are shown in Table 1.

The dataset comprises a panel of 30 countries during the 1980–2014 period and includes data on CO_2 emissions, economic growth, renewable and non-renewable energy consumption, technological innovation, per capita GDP, foreign direct investment, financial development, trade openness and population size. The variables data are chosen to cover as many countries as possible. Map 1 lists the 30 countries included in the model, which are distributed across the seven continents (Table 2).

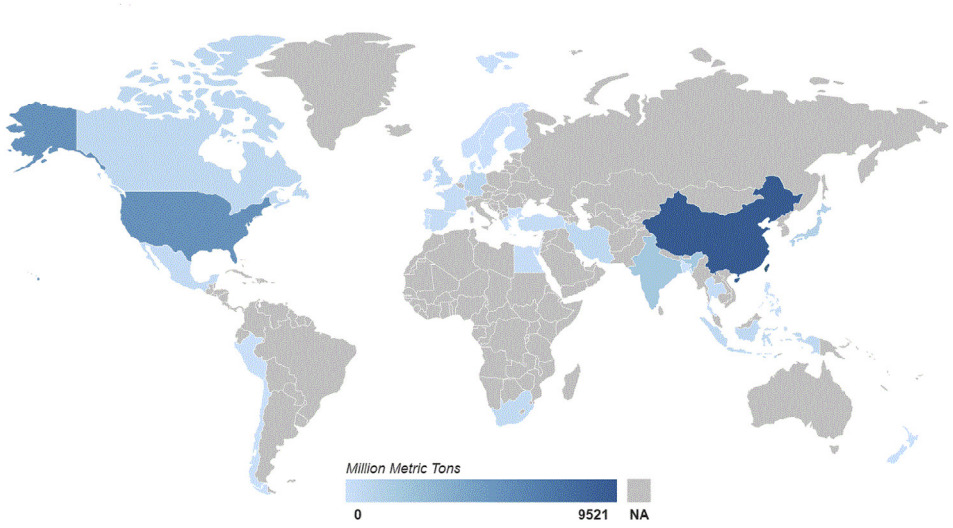
3.2.2. Data description

The statistical descriptions of all variables in the model are presented in Table 3. Recall that the skewness coefficient equals 0 for a symmetric distribution, while the kurtosis coefficient equals 3 for the normal distribution. The results show that the distributions of variables are skewed and more concentrated than the normal distribution with longer tails. Therefore, the OLS regression approach may yield biased results. Besides, the Jarque-Bera statistical test results indicate the non-normality of the unconditional distribution of variables. This is an additional finding that supports our use of the quantile regression approach to describe the complete picture of the heterogeneous impacts of the influences factors on CO_2 emissions in this paper.

According to the scatter plots (Fig. 1) which describe the link between CO_2 emissions and its driving factors, it visualizes a lot of linear and non–linear relationships. Therefore, adopting the quantile regression method to estimate the impacts of the driving forces on CO_2 emissions is reasonable and applicable.

4. Results

To study the heterogeneity of the effect of influence factors on different levels of CO_2 emissions and avoid omitted-variable bias, we develop our quantile regression model with relevant control variables. In this section, first, we conduct the stationarity test. Then, we implement the panel cointegration test between CO_2 emissions and its driving factors. Last, we present the results of the



Map 1. The CO_2 emissions from the selected countries in 2014.
Data Source: U.S. Energy Information Administration.

quantile regression model.

4.1. Panel unit root test

Before using the panel quantile regression model, the panel unit root test is used to test the stationarity of variables. LLC (Levin–Lin–Chu) test and Breitung test are first kind of panel data unit root tests which assume that the different cross–section sequences in panel data have a common unit root process. The secondtype is the unit root test with different roots including IPS (Im–Pesaran–Skin) test, Fisher–ADF test and Fisher–PP test. Results of the panel unit root tests is presented in Table 4. These results show that we could not be rejected the null hypothesis of the existence of a unit root at the 5% level. Since all variables are non-stationary, a differencing method is used to eliminate the non-stationary trend. The results show that the null hypothesis could almost be completely rejected at the 5% level. Thus, it can be concluded that all the variables are stationary at first-order difference.

4.2. Panel co-integration results

As indicated by the results of the panel unit root test, all variables are stationary at their first differences. Thus, Johansen Fisher panel cointegration test is used to examine the long-run relationship among variables. The results obtained from the trace test and max-eigen test are reported in Table 5. The results suggest that there are at least two cointegration relationships between CO_2 emissions and all the explanatory variables.

4.3. Panel quantile regression results

To illustrate the advantages of panel quantile regression model, OLS estimation results are also listed in the second columns of Table 6. The estimated results of the panel quantile regression are provided in Table 6 and Figs. 2–5. The results indicate that the coefficients of non-renewable energy consumption and per capita GDP on CO_2 emissions are positive and significant in the OLS regression. The impact of renewable energy consumption on CO_2 emissions is negative. However, the coefficient of technological innovation is insignificant in the OLS regression model. Additionally, the results (Fig. 2) provide evidence that the OLS regression results provide only an incomplete description of the effects of determinants on CO_2 emissions compared with the panel quantile regressions. A comparison of the OLS method and quantile regression results indicates that effects of the driving factors on emission are heterogeneous among countries with different levels of CO_2 emissions. Therefore, it is appropriate to use the panel quantile regression method to investigate the relationships among variables.

The quantile regression results based on Equation (5) are shown in Table 6, and they highlight several important findings. Regarding the impacts of energy consumption by source, increases in non-renewable energy consumption increase the level of CO_2 emissions. Moreover, compared with other driving factors, the non-renewable energy consumption has the greatest positive effect on CO_2 emissions across quantiles. These results are consistent with the findings of [74] for EU countries [23], for 27 advanced countries [15], for MENA countries [47,75], for OECD countries and [76] for 19 developed and developing countries. In addition, there are significant differences in the effect of non-renewable energy consumption on CO_2 emissions across lower and higher quantiles in the conditional distribution of CO_2 emissions. The influential intensity of non-renewable energy consumption on CO_2 emissions increases from 0.9486 to 1.125 and shows a rising trend (Fig. 2). For the high-emissions countries (such as China, United States, Canada and India), the non-renewable energy consumption has been increasing significantly in the past decades, and result in the increase of CO_2 emissions. While, at lower quantiles which refer to those lower CO_2 emission countries (such as Norway, Ireland, New Zealand, Chile, Denmark and Sweden), the growth rate of non-renewable energy consumption is quite slow over time during the sample period, thus the effect of non-renewable energy consumption on CO_2 emissions becomes relatively small.

Based on Fig. 3, the renewable energy consumption have a negative impact on CO_2 emission. This result is line with the those empirical reported by Ref. [50] for EU countries [23], for 27 advanced countries [18,47,75], for OECD countries [77], for Turkey and [24] for Kenya. However, this finding contrasts with the positive relationship between renewable energy consumption and CO_2 emissions found by Ref. [74] for EU countries [15], for MENA Region and [76] for a group of 19 developed and developing countries. This result is different from the findings of [78], who concluded that the use of renewable energy failed to mitigate CO_2 emissions in US. Moreover, the effect of renewable energy consumption on CO_2

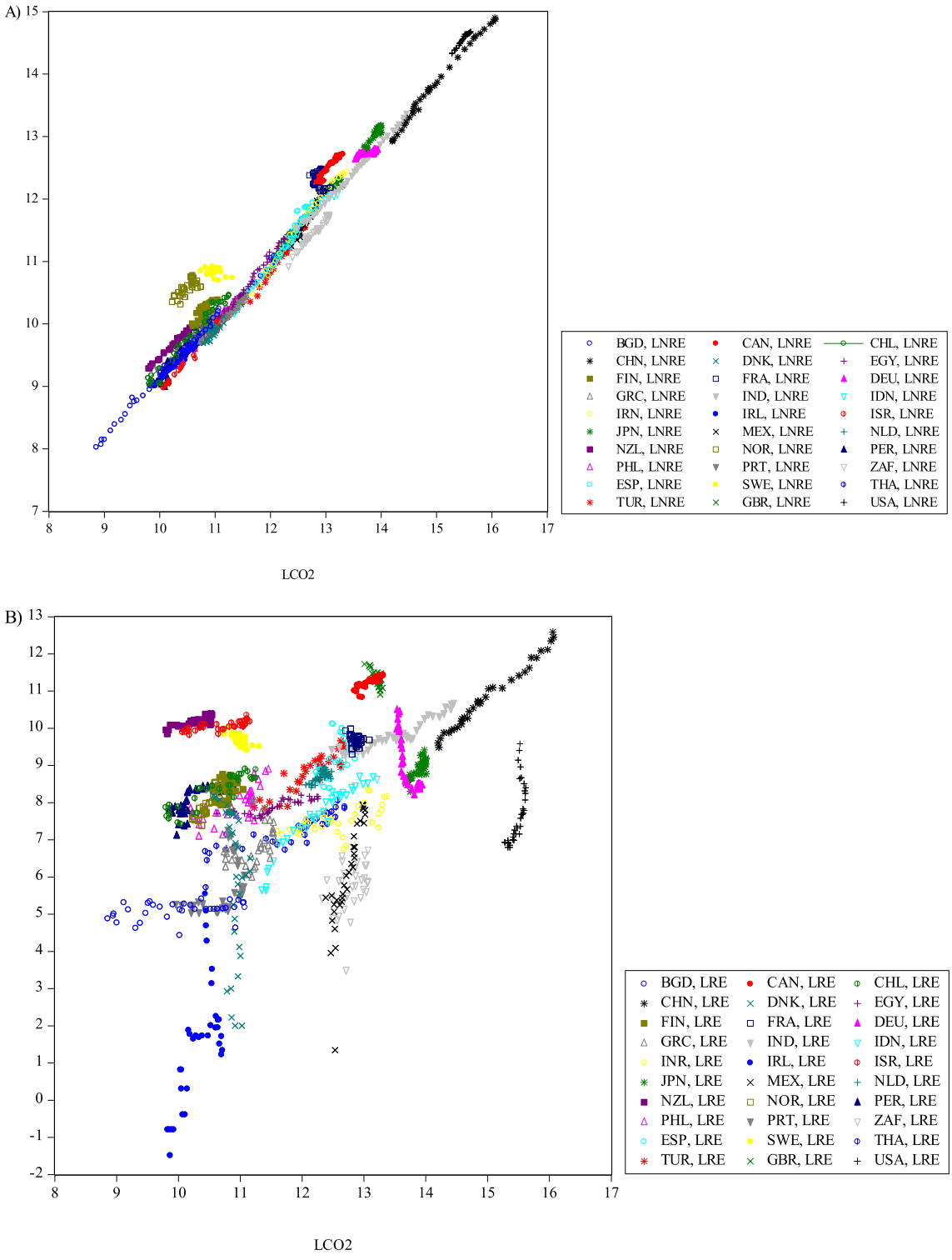


Fig. 1. Scatter chart of the links between the effect factors and CO_2 emissions.

emissions is heterogeneous: the impacts of renewable energy consumption on CO_2 emissions in the upper quantiles are smaller than those in the lower quantiles. For the high- CO_2 -emissions countries, non-renewable energy consumption controls carbon emissions, whereas the function of renewable energy consumption is limited in reducing carbon emissions. This is mainly because fossil energy is still the main source of energy in these high-emissions countries, and the use and proportion of renewable energy is insufficient.

In 2014, the largest CO_2 producers were the United States Russia, India and China which is the biggest emitter. For instance, according to the EIA, the total energy-related CO_2 emissions in China

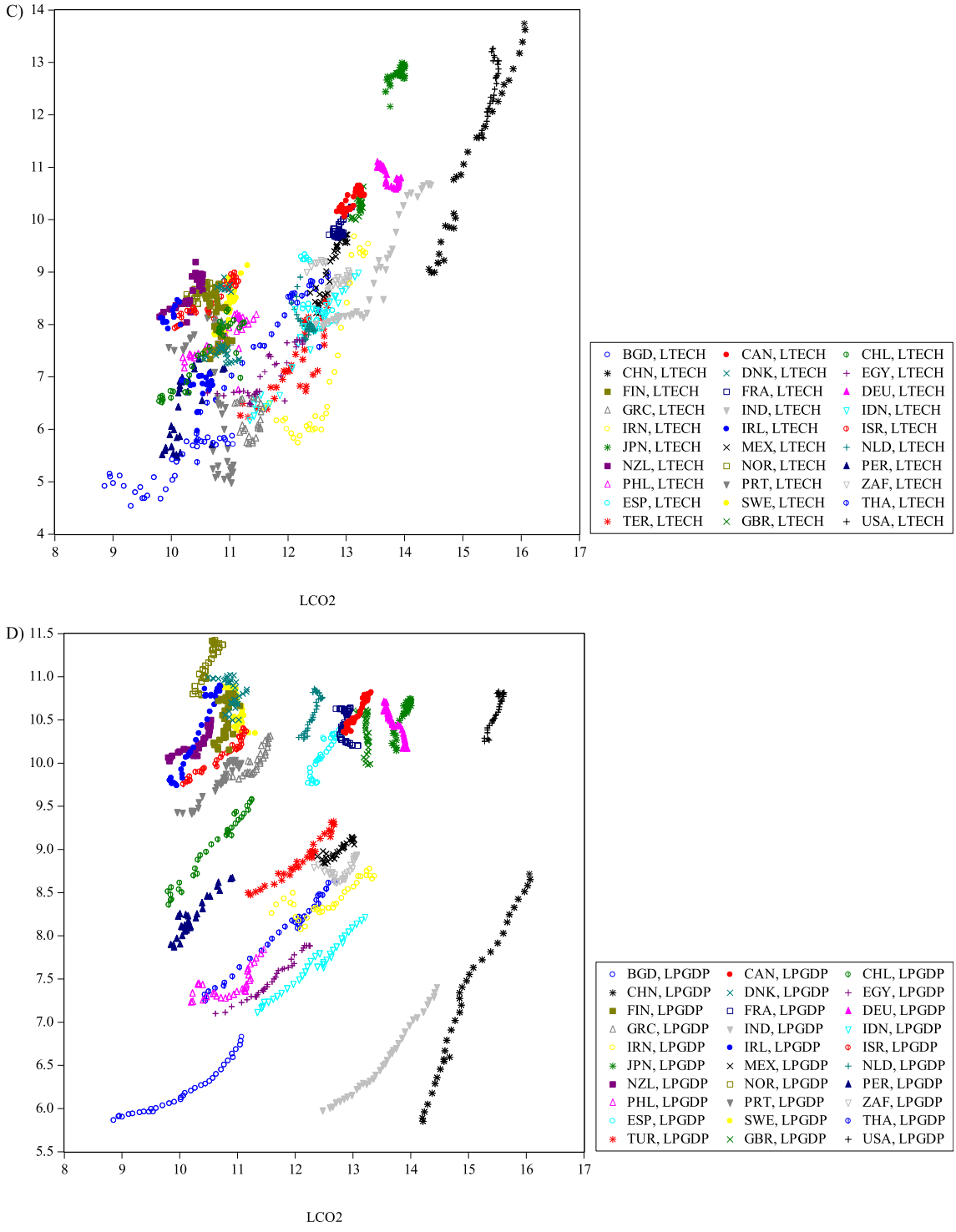


Fig. 1. (*continued*).

reached 9376 million tons in 2014, accounting for 27.79% of the world's total emissions. Thus, Chinese government has taken measures to change the energy structure. The renewable energy use in China has a growth trend as it an average annual growth rate of 8.99%. Although China ranks at the top in the world in terms of renewable energy use with the increasing adoption of renewable energy resources, the share of non-renewable energy in total primary energy consumption has been more than 88% over the last two decades. In the US case [78], pointed out that the share of renewables in total energy consumption increased only marginally. However, regarding to the lower CO_2 emission countries, such as, Israel and New Zealand, the proportion of the use of renewable energy is more than 50%. In fact [79], found that the threshold level of proportion of renewable energy in the total energy use is at least 8.3889% which it can mitigate CO_2 emissions largely. Therefore, according to the effects of energy consumption on CO_2 emissions are heterogeneous in different countries, to effectively reduce CO_2 emissions, the high- CO_2 -emissions countries strive to not only

Table 4
Panel unit root test.

Variable	Statistic	Levels					First difference				
		LLC	Breitung	IPS	Fisher-ADF	Fisher-PP	LLC	Breitung	IPS	Fisher-ADF	Fisher-PP
LCO_2	value	−1.527	0.432	−1.850	16.842	47.070	−6.231	−3.644	−5.492	45.220	45.307
	Prob.**	0.063	0.667	0.032	0.078	0.000	0.000	0.000	0.000	0.000	0.000
LPGDP	value	−1.896	0.772	−0.927	17.050	9.614	−5.588	−4.384	−5.003	42.148	35.417
	Prob.**	0.029	0.780	0.177	0.073	0.475	0.000	0.000	0.000	0.000	0.000
LNREC	value	−0.522	0.502	0.434	8.524	50.880	−7.635	−5.976	−6.443	52.184	51.805
	Prob.**	0.301	0.692	0.668	0.578	0.000	0.000	0.000	0.000	0.000	0.000
LREC	value	−1.793	2.253	−2.606	39.788	8.063	−1.646	−3.358	−3.638	31.650	37.206
	Prob.**	0.037	0.988	0.005	0.000	0.623	0.050	0.000	0.000	0.001	0.000
LTP	value	−1.107	−0.878	−1.484	14.760	38.396	−5.638	−3.485	−6.499	53.135	82.932
	Prob.**	0.134	0.190	0.069	0.141	0.000	0.000	0.000	0.000	0.000	0.000
TR	value	2.500	−1.225	−1.746	18.340	21.473	−4.313	−3.632	−3.622	34.712	109.785
	Prob.**	0.994	0.110	0.040	0.050	0.018	0.000	0.000	0.000	0.000	0.000
IS	value	−1.262	−0.324	0.145	10.648	4.245	−6.401	−6.187	−6.612	53.917	63.020
	Prob.**	0.103	0.373	0.558	0.386	0.936	0.000	0.000	0.000	0.000	0.000
FDI	value	−1.208	−2.337	−1.787	20.304	25.470	−6.675	−6.378	−7.935	65.122	308.830
	Prob.**	0.113	0.010	0.037	0.027	0.005	0.000	0.000	0.000	0.000	0.000
Fina	value	−0.235	0.117	0.738	7.218	11.323	−4.166	−4.613	−3.590	33.085	91.216
	Prob.**	0.407	0.547	0.770	0.705	0.333	0.000	0.000	0.000	0.000	0.000

Table 5
Johansen Fisher panel cointegration test.

Hypothesized No. Of CE(s)	Stat.[a] from trace test	Prob.	Stat.[a]from max-eigen test	Prob.
None	372.2	0.000	252.2	0.000
At most 1	176.2	0.000	118.1	0.000
At most 2	96.39	0.002	65.47	0.293
At most 3	72.43	0.130	60.14	0.471
At most 4	80.97	0.037	80.97	0.037

[a] Probabilities are computed using asymptotic Chi-square distribution.

Table 6
Quantile regression results of driving factors on CO_2 emissions.

Variables	OLS	Quantile regressions								
		10th	20th	30th	40th	50th	60th	70th	80th	90th
LNRE	1.02639*	0.96930*	1.03544*	0.98822*	0.95406*	0.95882*	0.94865*	1.04490*	1.11623*	1.12541*
LRE	−0.03425*	−0.06910*	−0.05123*	−0.04355*	−0.03177*	−0.0322*	−0.02112*	−0.02279*	−0.01138*	−0.01622*
LTECH	−0.00158	0.00436	0.00386	−0.00803*	−0.0080*	−0.01225*	−0.02240*	−0.03750*	−0.04836*	−0.04732*
LPGDP	0.13875*	0.22627*	0.15909*	0.12646*	0.11678*	0.09731*	0.09376*	0.02926*	0.01709*	0.00390*
FINA	−0.00038	−0.00683*	0.00112*	0.00168*	−0.0005*	0.00063*	0.00016	0.00163	0.00324*	−0.00187*
TR	0.00043	0.00205*	0.00138*	0.00079*	0.00077*	0.00078*	0.00106*	0.00043*	−0.00051*	−0.00064*
FDI	−0.00024*	0.00029*	0.00072*	0.00048*	0.00044*	−0.00006*	−0.00027*	−0.00039*	−0.00025*	−0.00006*
LPOP	0.12175*	0.04671*	0.03363*	0.10208*	0.13124*	0.12977*	0.15366*	0.09468*	0.13427*	0.15321*

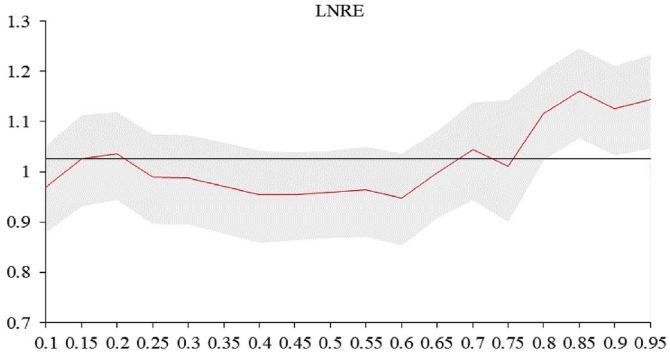


Fig. 2. Panel quantile regressions coefficients of non-renewable energy consumption. Note: The black solid line represents the corresponding OLS estimate coefficient.

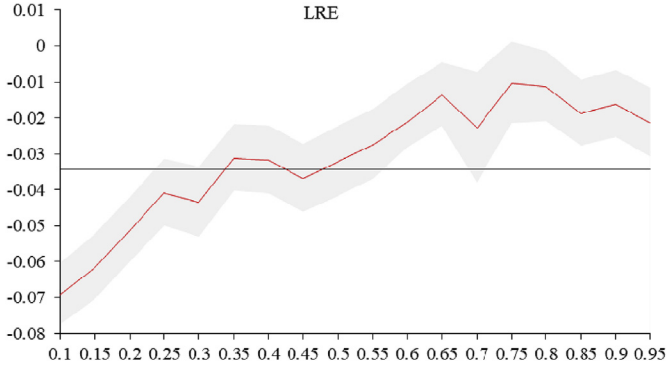


Fig. 3. Change in panel quantile regressions coefficients of renewable energy consumption.

increase the renewable energy consumption but also enhance the share of clean and renewable energy, while the low-emissions countries should further rely on the renewable energy to meet

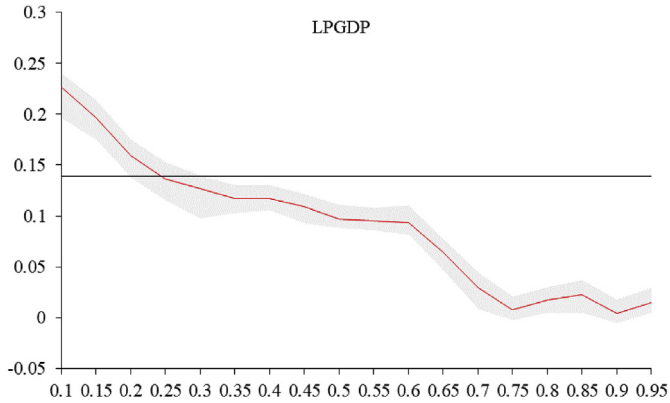


Fig. 4. Change in panel quantile regressions coefficients of per capita GDP.

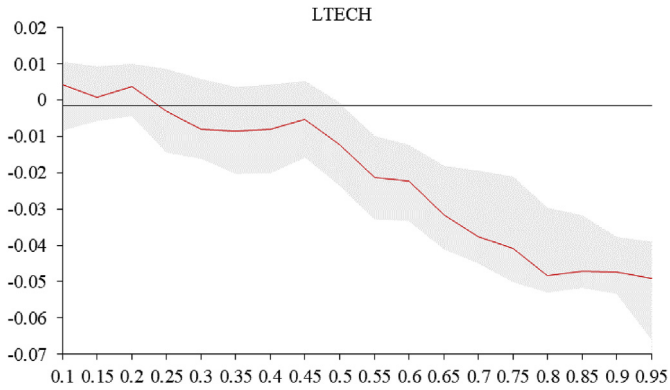


Fig. 5. Change in panel quantile regressions coefficients of technological innovation.

energy demand.

The other finding is that the PGDP coefficients are highly significant and have a positive sign in various quantiles (Table 6), this finding is similar to the results of [30,31,36,39,80–82]. However, this finding contrasts with the negative relationship between economic growth and CO_2 emissions found by Ref. [83] for Italy. Moreover, the effects of economic growth on CO_2 emissions continuously decrease from the lower-quantile countries to the upper-quantile countries (Fig. 4). It indicates that with more CO_2 emissions, economic growth will exert a smaller influence. Because, when the economic develops, the contradiction between and environmental pollution and economic growth also escalate gradually. Consequently, the rapid growth of economic has promoted the rapid increase in carbon emissions. However, for the high-emissions countries which the economy stay at the high stage of development, the environmental regulations of government would be improved. In these high-emissions countries, although CO_2 emissions have steadily increased, the energy intensity has decreased. For instance, China is the world's largest carbon emissions country, the change of China's economic growth mode makes the economic growth rate higher than the energy consumption. Therefore, the energy intensity of China has been decreasing from 10.9 (tce/yuan) in 1985 to 4.15 (tce/yuan) in 2014, which decreases the energy intensity and inhibits the increasing rate of carbon emissions. Similarly [84], obtained that income does not Granger cause the carbon emissions in the US. Therefore, the economic growth is not the main cause of growing CO_2 emissions for these high-emissions countries.

Additionally, the effect of technological innovation on CO_2 emissions is negative. Technological innovation has become a

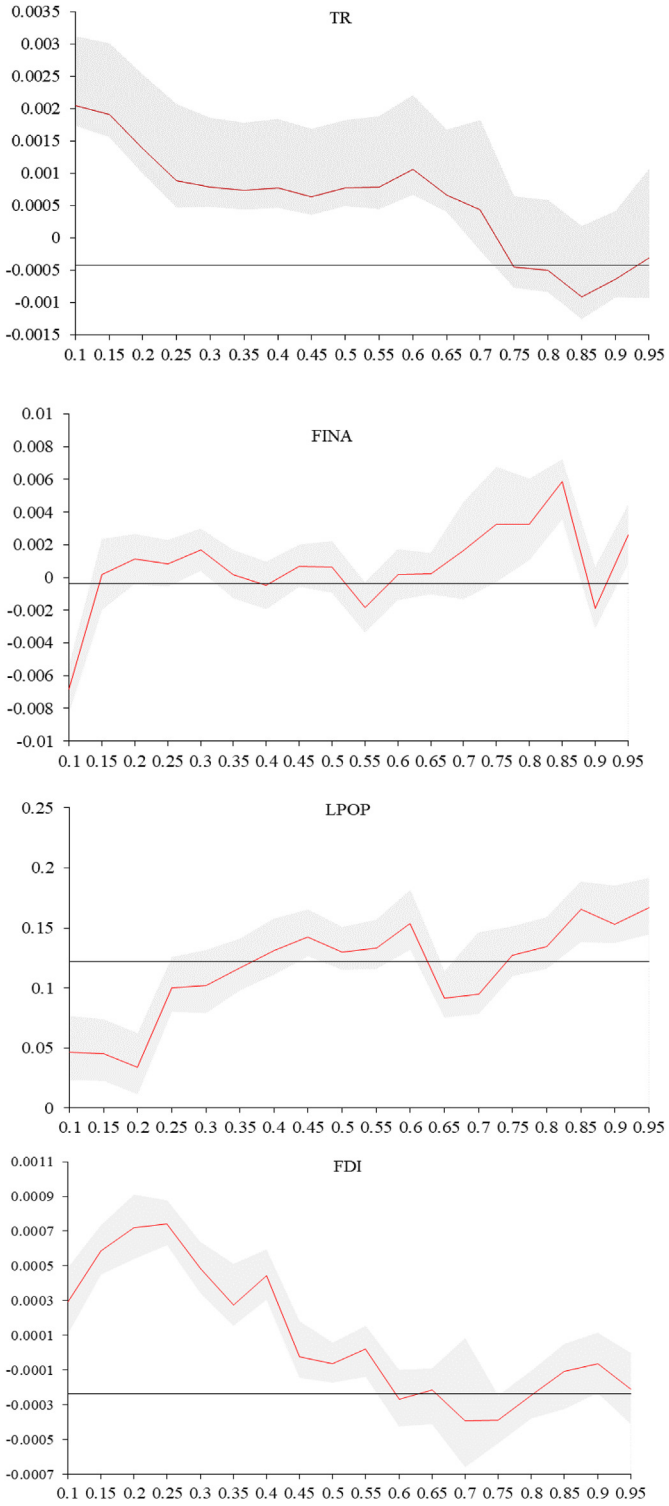


Fig. 6. Change in panel quantile regressions coefficients of control variables.

crucial element in the promotion of energy conservation, the reduction of CO_2 emissions and the substitution of fossil fuels with renewable energy. In fact [85,86],emphasized the importance of technology innovation in the development of renewable energy sector. Moreover, technological innovation is crucial for improving energy efficiency and reducing energy consumption [12,13,53,85,87,88]. Moreover, for the countries that have relatively

higher CO_2 emissions, the effect of technological innovation has a greater negative impact on CO_2 emissions than in low-emissions countries (Fig. 5). For high-emissions countries, rapid economic growth consumes more energy than that in low-emissions countries, which implies that there is a further improvement for energy technology to improve energy efficiency and increase the proportion of renewables in these high-emissions and high-income countries. These high-emissions countries have invested heavily in advanced energy technology. As a result, the technological progress is the main factor for reducing carbon emissions. The IEA has reported that investments in renewable energy technologies in the power sector will increase from $270 billion in 2015 to $400 billion in 2030. Among the high-emissions countries, China made the largest renewable energy investments in 2014 which is $83.3 billion, up 39% from 2013. And, the US invested a total of $38.3 billion, up 7% in one year. Japan was third at $35.7 billion, which was 10% higher than in 2013. Therefore, in order to effectively reduce carbon emissions, the high-emissions countries should increase investment in advanced energy-saving technology and encourage the development of the technology innovation.

4.4. The results of control variables

The panel quantile regression diagrams of control variables included in the model are provided in Fig. 6. First, there is a clear positive relationship between population and CO_2 emissions, as findings in the literature have indicated previously. Second, the financial development coefficient is positive and significant in the low and high quantiles except for the 10th, 40th and 90th. Financial development helps the economic growth, which results in more energy use and increasing CO_2 emissions. The similar result is supported by Refs. [33,39,89]. However, financial sector development also boosts investment in energy efficient technologies, thereby reducing CO_2 emissions. This result is in line with the finding by Refs. [90–93].

Regarding the effects of FDI and trade openness on CO_2 emissions are clearly significant and positive at low quantiles. The results are consistent with those reported by Refs. [25,79,94]. For the low-emissions countries, increases in trade openness and more FDI can lead to higher GDP, higher energy consumption and higher levels of CO_2 emissions. Moreover, FDI could largely promote CO_2 emissions with relaxed environmental standards [30]. Therefore, the low-emissions countries should evaluate the environmental impact of FDI before introducing foreign investors into the country. However, for the high-emissions countries, FDI and trade openness both have negative impacts on CO_2 emissions. The results are similar to the findings of [2,46,48,95–98]. Because increases in FDI increases energy efficiency through the adoption of new technologies, leading to lower emissions. Additionally, due to the technology spillover through trade flows, and these high-emissions and economically developed countries have made progress in developing new technologies and adopting environmentally friendly technologies over the last few decades. Thus, the impact of trade openness on the CO_2 emissions is negative. Therefore, the high-emissions countries could improve the level of FDI to mitigate the environment pollution to some extent.

5. Conclusion and suggestions

In this paper, a panel quantile regression model is developed to investigate the effects of economic growth, technological innovation, and renewable and non-renewable energy consumption on CO_2 emissions for global 30 countries during 1980–2014. This analysis extends the traditional panel regression method to consider the unobserved individual and distributional heterogeneities. Additionally, in order to overcome omitted-variable bias, related control variables are selected in the model. Therefore, this method could describe the relationships between CO_2 emissions and its influencing factors at different emissions levels. Based on the empirical results, several important conclusions are drawn, as follows.

5.1. Conclusions

(1) The results show that the impacts of driving factors on CO_2 emissions are heterogeneous. A comparison between conventional panel regression results and panel quantile regression with fixed effect results has emphasized the importance of considering the distributional heterogeneity of CO_2 emissions. This finding shows that the results of conventional panel regression under- or over-estimate the effect of driving factors on CO_2 emissions. In this paper, distributional analysis results could provide the scientific basis for policy-maker to target policies to specific country with different level of CO_2 emissions rather than to the entire group.

(2) Regarding the energy consumption by source, the non-renewable energy use has the greatest effect on carbon emissions across the quantiles. These results are consistent with the findings of [15,23,46,47,74,76]. The renewable energy consumption have a negative impact on CO_2 emission. This result is line with those empirical reported by Refs. [14,18,23,47,75,77]. However, this finding contrasts with those of [15,17,76]. Moreover, for the high emissions countries, the effect strength of non-renewable energy consumption on CO_2 emissions is stronger than in low-emissions countries. On the contrary, the influence strength of renewable energy consumption on CO_2 emissions is larger when the level of CO_2 emissions is relatively lower. Because non-renewable energy are still dominant in energy consumption structure in these high-emissions countries. Moreover, despite the increased level of renewable energy consumption, the mitigating effect on CO_2 emissions is limited due to the smaller proportion of renewable energy use in energy mix.

(3) The impact of economic growth on CO_2 emissions is positive. This result is similar to the findings of [30,31,36,39,80–82]. However, this finding contrasts with the negative relationship between economic growth and CO_2 emissions found by Ref. [83] for Italy. In addition, the effect strength of economic growth on CO_2 emissions continuously decreases from the low-emissions countries to the high-emissions countries, implying that with more CO_2 emissions, economic growth will exert a smaller influence. There are two main reasons, first, for the high-emissions countries which the economy stay at the high stage of development, the environmental regulations of government would be improved. Second, economic growth requires energy consumption as well as adds investments in renewable energy technologies. Therefore, low-carbon economy model could alleviate contradiction between environment pollution and economic growth.

(4) The effect of technological innovation has a greater negative effect on CO_2 emissions in the countries with relatively higher CO_2 emissions than in the low-emissions countries. This finding is observed because technological innovation has become a crucial element in improving energy efficiency and reducing energy consumption [12,13,53,85,87,88]. These high-emissions countries have invested heavily in advanced energy technology. As a result, the technological progress is the main factor for reducing carbon emissions and the

substitution of non-renewable energy with renewable energy for the countries that have relatively higher CO_2 emissions.

(5) For the low-emissions countries, increases in trade and more FDI can lead to economic growth and increasing energy consumption, ultimately, the higher levels of CO_2 emissions. However, the trade development and greater FDI mitigate CO_2 emissions in the high- CO_2 -emissions countries because there is technology spillover through trade flows and because increases in FDI help to increase energy efficiency through the adoption of new technologies that lead to lower emissions.

In future work, we focus on the relationship between technological innovation and the renewable energy consumption in different country. How is it possible to stimulate technological innovation and raise the use of renewable energy to achieve emission-reducing and low carbon economy objectives?

5.2. Suggestions

The demand for non-renewable energy resulting from increased economic growth will accelerate the generation of CO_2 emissions, especially the high-emissions countries. Thus, the high- CO_2 -emissions countries strive to reduce consumption and reliance on fossil fuels and add renewable sources to their energy mixes to cut down on pollution. Because, the renewable energy consumption could effectively mitigate carbon emissions in low-carbon countries, thus, they should improve the proportion of renewable energy sources to meet energy needs. Another option to control CO_2 emissions is increasing investment in the technological sector to provide opportunities to import new technologies. Thus, technological innovation could result in consuming from renewable energy at lower costs and increasing energy efficiency. Moreover, transforming the economic growth mode is helpful to transfer from non-renewable to renewable sources of energy to meet energy demand and effectively reduce CO_2 emissions. In addition, according to the effects of FDI on CO_2 emissions are heterogeneous in different countries, the high-emissions countries could improve the level of FDI to mitigate the environment pollution to some extent, while the low-emissions countries should evaluate the environmental impact of FDI before introducing foreign investors into the country.

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Appendix

Table 1
Studies focusing on total energy consumption in environment-energy-growth literature.

Author	Country	Year	Variables	Methods	Results	EKC Hypothesis
[30]	Russia	1990–2007	CO_2, EC, GDP, GDP^2	Johansen cointegration, OLS, VECM	EC contributes to CO_2; EC↔GDP; GDP↔CO_2, EC↔CO_2	No
[31]	China	1995–2009	CO_2, EC, GDP, GDP^2,URB, TI	OLS with FE, GMM	TI, GDP→ CO_2	No
[32]	USA	1960–2010	CO_2, EC, GDP, GDP^2,TR, URB, FD	ARDL, VECM causality	EC and URB contribute to CO_2, TR mitigates CO_2, CO_2↔GDP; EC↔CO_2; TR↔GDP; CO_2↛TR; GDP→EC	No
[6]	Turkey	1960–2000	CO_2, EC, GDP	Granger causality	CO_2→EC; GDP↛CO_2	Not investigated
[99]	Malaysia	1971–1999	CO_2, EC, GDP	VECM causality	CO_2→GDP; GDP↔EC	Not investigated
[100]	China	1990–2012	CO_2, EC, GDP	VECM	EC and GDP contribute to CO_2	Not investigated
[25]	EU Countries	1992–2010	CO_2, EC, GDP, GDP^2, TR, URB	FMOLS, Granger causality	EC, TR and URB contribute to CO_2; GDP↔CO_2, EC↔CO_2, TR↔CO_2, GDP↔EC	Yes
[39]	Turkey	1974–2010	CO_2, EC, GDP, GDP^2, FD	ARDL, VECM causality	EC and FD contribute to CO_2; EC, GDP → CO_2; FD↔CO_2	Yes
[33]	BRIC countries	1992–2007	CO_2, EC, GDP, GDP^2,FD	OLS	FD and EC contribute to CO_2;EC↔GDP; GDP↔CO_2	Yes
[38]	Turkey	1974–2010	CO_2, EC, GDP,FD	ARDL	EC and FD contribute to CO_2	Yes
[36]	China	1996–2012	CO_2, EC, GDP, GDP^2,TR, URB	GMM	EC, TR and URB contributes to CO_2	Yes
[37]	Canada	1948–2004	CO_2, GDP	PLS	positive correlation	Yes

Table 2
Studies about energy consumption by sources in environment-energy-growth literature

Author	Country	Year	Variables	Methods	Results
[17]	EU countries	1990–2008	CO_2, GDP, GDP^2, REC, NREC	OLS with FE	REC and NREC contribute to CO_2
[50]	EU countries	1996–2010	CO_2, GDP, GDP^2, GDP^3, REC	OLS with FE, RE	REC mitigates CO_2
[23]	Panel of 27 advanced countries	1990–2012	CO_2, GDP, GDP^2,REC, NREC, TR, URB, P	FMOLS	REC mitigates CO_2, NREC contributes to CO_2
[15]	MENA countries	1980–2009	CO_2, GDP, GDP^2, REC, NREC	FMOLS, DOLS	REC and NREC contribute to CO_2
[101]	OECD countries	1977–2010	CO_2, GDP, GDP^2,REC	FMOLS, DOLS	REC mitigates CO_2
[75]	OECD countries	1980–2010	CO_2, GDP, GDP^2, REC, NREC, TR	FMOLS, DOLS	REC and TR mitigate CO_2; NREC contributes to CO_2

(*continued on next page*)

Table 2 (*continued*)

Author	Country	Year	Variables	Methods	Results
[102]	OECD countries	1980–2011	CO_2, GDP, GDP^2, REC, NREC, POP	GMM, AMG	REC mitigates CO_2; NREC contributes to CO_2
[77]	Turkey	1961–2010	CO_2, GDP, GDP^2, REC	ARDL	REC mitigates CO_2
[24]	Kenya	1980–2012	CO_2, Y, REC, NREC, TR,FD, UB	ARDL	REC and FD mitigates CO_2 NREC, TR and URB contributes to CO_2
[48]	Malaysia	1980–2009	CO_2, GDP, GDP^2, REC, TR	ARDL	TR and REC mitigate CO_2
[79]	OECD countries	1996–2005	CO_2, GDP, CPI, REC	Threshold effect	GDP and REC contribute to CO_2 for lower threshold; REC mitigates CO_2 for upper threshold.
[103]	Panel of developed and developing countries	1984–2007	CO_2, GDP, Nuclear, REC	Cointegration test	Nuclear mitigates CO_2, REC and CO_2 contribute to CO_2
[104]	USA, Japan, France, Korea, Spain, Canada	1970–2007	CO_2, GDP, Nuclear	Johansen cointegration	Nuclear mitigates CO_2 in all countries, GDP mitigates CO_2 in USA, Canada and France
[105]	Italy	1960–2011	CO_2, GDP, REC, NREC, TR	Gregory-Hansen cointegration, ARDL model	REC and GDP mitigate CO_2, NREC contributes to CO_2
[19]	South America	1980–2010	CO_2, GDP, P, REC	FMOLS, Granger causality	GDP↔REC; CO_2↔GDP; CO_2↔REC;
[78]	USA	1960–2007	CO_2, GDP, Nuclear, REC	Toda-Yamamoto causality	Nuclear→ CO_2, CO_2→REC, GDP→REC, CO_2↔GDP
[106]	USA	1965–2012	NUC, RE, CO_2 and GDP	VECM Granger causality	REC→ CO_2
[107]	BRICS countries	1971–2010	REC,GDP,TR, CO_2	ARDL	REC↔GDP; CO_2→REC
[22]	7 Central American countries	1980–2010	REC,GDP, COAL PRICE, OIL PRICE	FMOLS and Regime-wise Granger-causality Tests	REC↔GDP REC↔ CO_2

Table 3
Studies about the effect of technological innovation on environment-energy-growth nexus.

Author	Country	Year	Variables	Methods	results
[16]	China	1978–2008	GDP,REC,K, L, R&D	OLS	REC, K and R&D increase GDP
[45]	OECD countries	1990–2010	GDP,REC,K, L, R&D	OLS with FE	REC, K, L, R&D increase GDP
[52]	four Nordic countries	1975–2012	GDP, R&D,CO_2,REC	VAR	R&D→REC, GDP→REC
[53]	Malaysia	1970–2009	TI, GDP, CO_2, CE	ARDL	TI mitigate NREC
[73]	New Zealand and Norway	1971–2010	TI, GDP, CO_2, CE	ARDL	TI affects clean energy-growth nexus
[13]	Malaysia	1980–2012	TI, EC, GDP,TR	ARDL	TI reduce EC

Note: CE(clean energy), EC(energy consumption), REC(renewable energy consumption), NREC (non-renewable energy consumption); R&D(Research and Development); OLS (Ordinary Least Squares), FMOLS (Fully Modified Ordinary Least Squares), DOLS (Dynamic Ordinary Least Squares), FE(Fixed effects), RE(Random effects), GDP (economic growth), CPI (consumer price index),P (population), TR (trade openness), FD (financial development), TI(technological innovation) URB (Urbanization), K (capital), L (labor); ↔ (bidirectional Granger causality), → (unidirectional Granger causality), ↛ (no Granger causality).

References

[1] K. Saidi, M. Ben Mbarek, Nuclear energy, renewable energy, CO_2 emissions, and economic growth for nine developed countries: evidence from panel Granger causality tests, Prog. Nucl. Energy 88 (2016) 364–374.
[2] E. Dogan, F. Seker, The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries, Renew. Sustain. Energy Rev. 60 (2016) 1074–1085.
[3] P.-Y. Chen, S.-T. Chen, C.-S. Hsu, C.-C. Chen, Modeling the global relationships among economic growth, energy consumption and CO_2 emissions, Renew. Sustain. Energy Rev. 65 (2016) 420–431.
[4] Y.J. Zhang, The impact of financial development on carbon emissions: an empirical analysis in China, Energy Pol. 39 (4) (2010) 2197–2203.
[5] I. Ozturk, A. Acaravci, The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey,, Energy Econ. 36 (2013) 262–267.
[6] P. Sadorsky, Renewable energy consumption, $CO_{(2)}$ emissions and oil prices in the G7 countries, Energy Econ. 31 (3) (2009) 456–462.
[7] M.H. Amini, B. Nabi, M.R. Haghifam, Load management using multi-agent systems in smart distribution network, in: Power and Energy Society General Meeting, 2013, pp. 1–5.
[8] K.G. Boroojeni, M.H. Amini, A. Nejadpak, S.S. Iyengar, B. Hoseinzadeh, C.L. Bak, A theoretical bilevel control scheme for power networks with large-scale penetration of distributed renewable resources, in: IEEE International Conference on Electro Information Technology, 2016, pp. 0510–0515.
[9] E. Dogan, Analyzing the linkage between renewable and non-renewable energy consumption and economic growth by considering structural break in time-series data, Renew. Energy 99 (2016) 1126–1136.
[10] K. Fisher-Vanden, G.H. Jefferson, H. Liu, Q. Tao, What is driving China's decline in energy intensity? Resourc. Energy Economic. 26 (1) (2004) 77–97.
[11] L. Hang, M. Tu, The impacts of energy prices on energy intensity: evidence from China, Energy Pol. 35 (5) (2007) 2978–2988.
[12] Z. Nan, M.D. Levine, L. Price, Overview of current energy-efficiency policies in China, Energy Pol. 38 (11) (2010) 6439–6452.
[13] K. Sohag, R.A. Begum, S.M.S. Abdullah, M. Jaafar, Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia, Energy 90 (2015) 1497–1507.
[14] A. Jesus Lopez-Menendez, R. Perez, B. Moreno, Environmental costs and renewable energy: Re-visiting the environmental kuznets curve, J. Environ. Manag. 145 (2014) 368–373.
[15] S. Farhani, J. Ben Rejeb, Energy consumption, economic growth and CO_2 emissions: evidence from panel data for MENA region, Int. J. Energy Econ. Pol. 2 (2) (2012) 71–81.
[16] Y. Fang, Economic welfare impacts from renewable energy consumption: the China experience, Renew. Sustain. Energy Rev. 15 (9) (2011) 5120–5128.
[17] G. Bölük, M. Mert, Fossil & renewable energy consumption, GHGs (greenhouse gases) and economic growth: evidence from a panel of EU (European Union) countries, Energy 74 (2014) 439–446.
[18] F. Bilgili, E. Kocak, U. Bulut, The dynamic impact of renewable energy consumption on CO_2 emissions: a revisited Environmental Kuznets Curve approach,, Renew. Sustain. Energy Rev. 54 (2016) 838–845.
[19] N. Apergis, J.E. Payne, Renewable energy, output, carbon dioxide emissions, and oil prices: evidence from South America, Energy Sources B Energy Econ. Plann. 10 (3) (2015) 281–287.
[20] S. Dinda, D. Coondoo, Income and emission: a panel data-based cointegration analysis, Ecol. Econ. 57 (2) (2006) 167–181.
[21] U. Al-Mulali, B. Saboori, I. Ozturk, Investigating the environmental Kuznets curve hypothesis in Vietnam, Energy Pol. 76 (2015) 123–131.
[22] I. Ozturk, U. Al-Mulali, Investigating the validity of the environmental

Kuznets curve hypothesis in Cambodia, Ecol. Indicat. 57 (2015) 324–330.
[23] U. Al-Mulali, I. Ozturk, The investigation of environmental Kuznets curve hypothesis in the advanced economies: the role of energy prices, Renew. Sustain. Energy Rev. 54 (2016) 1622–1631.
[24] U. Al-Mulali, S.A. Solarin, I. Ozturk, Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach, Natural Hazards 80 (3) (2016) 1729–1747.
[25] A. Kasman, Y.S. Duman, CO_2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis, Econ. Modell. 44 (2015) 97–103.
[26] M. Sebri, O. Ben-Salha, On the causal dynamics between economic growth, renewable energy consumption, CO_2 emissions and trade openness: fresh evidence from BRICS countries, Renew. Sustain. Energy Rev. 39 (2014) 14–23.
[27] B. Lin, M. Moubarak, Renewable energy consumption – economic growth nexus for China, Renew. Sustain. Energy Rev. 40 (C) (2014) 111–117.
[28] A. Moheeldeen, Income-carbon emissions nexus for Middle East and North Africa countries: a Semi-parametric approach, Int. J. Energy Econ. Pol. 7 (2) (2017) 152–159.
[29] B. Saboori, A. Soleymani, CO_2 emissions, economic growth and energy consumption in Iran: a co-integration approach, Int. J. Environ. Sci. (2011).
[30] H.-T. Pao, C.-M. Tsai, Modeling and forecasting the CO_2 emissions, energy consumption, and economic growth in Brazil, Energy 36 (5) (2011) 2450–2458.
[31] L. Du, C. Wei, S. Cai, Economic development and carbon dioxide emissions in China: provincial panel data analysis, China Econ. Rev. 23 (2) (2012) 371–384.
[32] E. Dogan, B. Turkekul, CO_2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA, Environ. Sci. Pollut. Res. 23 (2) (2016) 1203–1213.
[33] H.-T. Pao, C.-M. Tsai, Multivariate Granger causality between CO_2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries, Energy 36 (1) (2011) 685–693.
[34] F. Seker, H.M. Ertugrul, M. Cetin, The impact of foreign direct investment on environmental quality: a bounds testing and causality analysis for Turkey, Renew. Sustain. Energy Rev. 52 (2015) 347–356.
[35] K. Gokmenoglu, N. Ozatac, B.M. Eren, Relationship between industrial production, financial development and carbon emissions: the case of Turkey ☆, Procedia Economics & Finance 25 (2015) 463–470.
[36] T. Li, Y. Wang, D. Zhao, Environmental Kuznets Curve in China: new evidence from dynamic panel analysis, Energy Pol. 91 (2016) 138–147.
[37] J. He, P. Richard, Environmental kuznets curve for CO_2 in Canada, Ecological Economics 69 (5) (2010) 1083–1093.
[38] K. Gokmenoglu, N. Ozatac, B.M. Eren, Relationship between industrial production, financial development and carbon emissions: the case of Turkey, Procedia Economics and Finance 25 (2015) 463–470.
[39] F. Seker, H.M. Ertugrul, M. Cetin, The impact of foreign direct investment on environmental quality: a bounds testing and causality analysis for Turkey, Renew. Sustain. Energy Rev. 52 (2015) 347–356.
[40] S. Wang, Q. Li, C. Fang, C. Zhou, The relationship between economic growth, energy consumption, and CO_2 emissions: empirical evidence from China, Sci. Total Environ. 542 (Pt A) (2016) 360–371.
[41] A. Omri, CO_2 emissions, energy consumption and economic growth nexus in MENA countries: evidence from simultaneous equations models, Energy Econ. 40 (2013) 657–664.
[42] C.T. Tugcu, A.K. Tiwari, Does renewable and/or non-renewable energy consumption matter for total factor productivity (TFP) growth? Evidence from the BRICS, Renew. Sustain. Energy Rev. 65 (2016) 610–616.
[43] F. Kula, The long-run relationship between renewable electricity consumption and GDP: evidence from panel data, Energy Sources Part B 9(2) (2014) 156–160.
[44] N. Apergis, J.E. Payne, Renewable energy, output, carbon dioxide emissions, and oil prices: evidence from South America, Energy Sources Part B 10 (3) (2015) 281–287.
[45] R. Inglesi-Lotz, The impact of renewable energy consumption to economic growth: a panel data Application, Energy Econ. 53 (2015) 58–63.
[46] M. Ben Jebli, S. Ben Youssef, I. Ozturk, Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries, Ecol. Indicat. 60 (2016) 824–831.
[47] S. Shafiei, R.A. Salim, Non-renewable and renewable energy consumption and CO_2 emissions in OECD countries: a comparative analysis, Energy Pol. 66 (2014) 547–556.
[48] J. Sulaiman, A. Azman, B. Saboori, The potentialof renewable energy: using the environmental kuznets curve model, Am. J. Environ. Sci. 9 (2) (2013) 103–112.
[49] N. Apergis, J.E. Payne, Renewable energy consumption and economic growth: evidence from a panel of OECD countries, Energy Pol. 38 (1) (2010) 656–660.
[50] A.J. López-Menéndez, R. Pérez, B. Moreno, Environmental costs and renewable energy: re-visiting the Environmental Kuznets Curve, J. Environ. Manag. 145 (1) (2014) 368.
[51] C.-L. Chiu, T.-H. Chang, What proportion of renewable energy supplies is needed to initially mitigate CO_2 emissions in OECD member countries? Renew. Sustain. Energy Rev. 13 (6–7) (2009) 1669–1674.
[52] M. Irandoust, The renewable energy-growth nexus with carbon emissions and technological innovation: evidence from the Nordic countries,, Ecol. Indicat. 69 (2016) 118–125.
[53] C.F. Tang, E.C. Tan, Exploring the nexus of electricity consumption, economic growth, energy prices and technology innovation in Malaysia, Appl. Energy 104 (4) (2013) 297–305.
[54] A. Jones, An environmental assessment of food supply chains: a case study on dessert Apples, Environ. Manag. 30 (4) (2002) 560–576.
[55] P.K. Narayan, R. Smyth, Multivariate granger causality between electricity consumption, exports and GDP: evidence from a panel of Middle Eastern countries, Energy Pol. 37 (1) (2009) 229–236.
[56] S. Rafiq, R. Salim, I. Nielsen, Urbanization, openness, emissions, and energy intensity: a study of increasingly urbanized emerging economies, Energy Econ. 56 (2016) 20–28.
[57] H.M. Zhu, L.J. Duan, Y.W. Guo, K.M. Yu, The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: evidence from panel quantile regression, Econ. Modell. 58 (2016) 237–248.
[58] R. Koenker, G. Bassett, Tests of linear hypotheses and l1 estimation, Econometrica 50 (6) (1982) 1577–1583.
[59] R. Koenker, Quantile regression for longitudinal data, J. Multivariate Anal. 91 (1) (2004) 74–89.
[60] C. Lamarche, Robust penalized quantile regression estimation for panel data, J. Econom. 157 (2) (2010) 396–408.
[61] A.F. Galvao Jr., Quantile regression for dynamic panel data with fixed effects, J. Econom. 164 (1) (2011) 142–157.
[62] I.A. Canay, A simple approach to quantile regression for panel data, Econom. J. 14 (3) (2011) 368–386.
[63] Y.J. Zhang, Y.L. Jin, J. Chevallier, B. Shen, The effect of corruption on carbon dioxide emissions in APEC countries: a panel quantile regression analysis, Technol. Forecast. Soc. Change 112 (2016) 220–227.
[64] U. Al-mulali, H.G. Fereidouni, J.Y.M. Lee, Electricity consumption from renewable and non-renewable sources and economic growth: evidence from Latin American countries, Renew. Sustain. Energy Rev. 30 (2014) 290–298.
[65] J.B. Ang, CO2 emissions, energy consumption, and output in France, Energy Pol. 35 (10) (2007) 4772–4778.
[66] N. Apergis, J.E. Payne, The electricity consumption-growth nexus: renewable versus non-renewable electricity in Central America, Energy Sources Part B 7 (4) (2012) 423–431.
[67] O. Damette, P. Delacote, On the economic factors of deforestation: what can we learn from quantile analysis? Econ. Modell. 29 (6) (2012) 2427–2434.
[68] M.A. Boutabba, The impact of financial development, income, energy and trade on carbon emissions: evidence from the Indian economy, Econ. Modell. 40 (C) (2014) 33–41.
[69] A. Kasman, Y.S. Duman, CO_2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis, Econ. Modell. 44 (44) (2015) 97–103.
[70] M. Sebri, O. Ben-Salha, On the causal dynamics between economic growth, renewable energy consumption, CO_2 emissions and trade openness: fresh evidence from BRICS countries, Renew. Sustain. Energy Rev. 39 (39) (2014) 14–23.
[71] W.H. You, H.M. Zhu, K. Yu, C. Peng, Democracy, Financial Openness, Global Carbon, Dioxide emissions: heterogeneity across existing emission levels, World Dev. 66 (2015) 189–207.
[72] H. Zhu, L. Duan, Y. Guo, K. Yu, The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: evidence from panel quantile regression, Econ. Modell. 58 (2016) 237–248.
[73] Q. Fei, R. Rasiah, J.S. Leow, The impacts of energy prices and technological innovation on the fossil fuel-related electricity- growth nexus: an assessment of four net energy exporting countries, J. Energy South Afr. 25 (3) (2014) 37–46.
[74] G. Boluk, M. Mert, Fossil & renewable energy consumption, GHGs (greenhouse gases) and economic growth: evidence from a panel of EU (European Union) countries, Energy 74 (2014) 439–446.
[75] M.B. Jebli, S.B. Youssef, I. Ozturk, Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries, Ecol. Indicat. 60 (2016) 824–831.
[76] N. Apergis, J.E. Payne, K. Menyah, Y. Wolde-Rufael, On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth, Ecol. Econ. 69 (11) (2010) 2255–2260.
[77] G. Bölük, M. Mert, The renewable energy, growth and environmental Kuznets curve in Turkey: an ARDL approach,, Renew. Sustain. Energy Rev. 52 (2015) 587–595.
[78] K. Menyah, Y. Wolderufael, CO_2 emissions, nuclear energy, renewable energy and economic growth in the US, Energy Pol. 38 (6) (2010) 2911–2915.
[79] C.L. Chiu, T.H. Chang, What proportion of renewable energy supplies is needed to initially mitigate CO_2 emissions in OECD member countries? Renew. Sustain. Energy Rev. 13 (6–7) (2009) 1669–1674.
[80] M. Ben Jebli, S. Ben, Youssef, the environmental Kuznets curve, economic growth, renewable and non-renewable energy, and trade in Tunisia, Renew. Sustain. Energy Rev. 47 (2015) 173–185.
[81] V.G.R. Chandran, C.F. Tang, The impacts of transport energy consumption, foreign direct investment and income on CO_2 emissions in ASEAN-5 economies, Renew. Sustain. Energy Rev. 24 (2013) 445–453.
[82] B. Ozcan, The nexus between carbon emissions, energy consumption and economic growth in Middle East countries: a panel data analysis, Energy Pol.

62 (2013) 1138–1147.
[83] J.P.C. Sento, V. Moutinho, CO_2 emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy, Renew. Sustain. Energy Rev. 55 (2016) 142–155.
[84] U. Soytas, R. Sari, B.T. Ewing, Energy consumption, income, and carbon emissions in the United States, Ecol. Econ. 62 (3–4) (2007) 482–489.
[85] C.D.V. Costa, E.L. Rovere, D. Assmann, Technological innovation policies to promote renewable energies: lessons from the European experience for the Brazilian case, Renew. Sustain. Energy Rev. 12 (1) (2008) 65–90.
[86] S. Silva, I. Soares, O. Afonso, Economic and environmental effects under resource scarcity and substitution between renewable and non-renewable resources, Energy Pol. 54 (3) (2013) 113–124.
[87] F. Jamil, E. Ahmad, Income and price elasticities of electricity demand: aggregate and sector-wise analyses, Energy Pol. 39 (9) (2011) 5519–5527.
[88] J. Pan, G. Zhuang, Y. Zheng, Clarification of the concept of low-carbon economy and analysis of its core elements, Int. Econ. Rev. (2010).
[89] S. Farhani, I. Ozturk, Causal relationship between CO_2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia, Environ. Sci. Pollut. Res. 22 (20) (2015) 15663–15676.
[90] A. Tamazian, J.P. Chousa, K.C. Vadlamannati, Does higher economic and financial development lead to environmental degradation: evidence from BRIC countries, Energy Pol. 37 (1) (2009) 246–253.
[91] U. Al-mulali, C. Weng-Wai, L. Sheau-Ting, A.H. Mohammed, Investigating the environmental Kuznets curve (EKC) hypothesis by utilizing the ecological footprint as an indicator of environmental degradation, Ecol. Indicat. 48 (2015) 315–323.
[92] A. Jalil, M. Feridun, The impact of growth, energy and financial development on the environment in China: a cointegration analysis, Energy Econ. 33 (2) (2011) 284–291.
[93] M. Shahbaz, S. Nasreen, F. Abbas, O. Anis, Does foreign direct investment impede environmental quality in high-, middle-, and low-income countries? Energy Econ. 51 (2015) 275–287.
[94] M. Shahbaz, N. Khraief, G.S. Uddin, I. Ozturk, Environmental Kuznets curve in an open economy: a bounds testing and causality analysis for Tunisia, Renew. Sustain. Energy Rev. 34 (2014) 325–336.
[95] E. Dogan, F. Seker, S. Bulbul, Investigating the impacts of energy consumption, real GDP, tourism and trade on CO_2 emissions by accounting for cross-sectional dependence: a panel study of OECD countries, Curr. Issues Tourism (2015).
[96] D. E, T. B, CO_2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA, Environ. Sci. Pollut. Res. Int. 23 (2) (2015) 1203–1213.
[97] M.S. Hossain, Panel estimation for CO_2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries, Energy Pol. 39 (11) (2011) 6991–6999.
[98] M. Shahbaz, Q.M.A. Hye, A.K. Tiwari, N.C. Leitao, Economic growth, energy consumption, financial development, international trade and CO_2 emissions in Indonesia, Renew. Sustain. Energy Rev. 25 (2013) 109–121.
[99] J.B. Ang, Economic development, pollutant emissions and energy consumption in Malaysia, J. Pol. Model. 30 (2) (2008) 271–278.
[100] S. Wang, Q. Li, C. Fang, C. Zhou, The relationship between economic growth, energy consumption, and CO_2 emissions: empirical evidence from China, Sci. Total Environ. 542 (2016) 360–371.
[101] F. Bilgili, E. Koçak, Ü. Bulut, The dynamic impact of renewable energy consumption on CO_2 emissions: a revisited Environmental Kuznets Curve approach, Renew. Sustain. Energy Rev. 54 (2016) 838–845.
[102] S. Shafiei, R.A. Salim, Non-renewable and renewable energy consumption and CO_2 emissions in OECD countries: a comparative analysis, Energy Pol. 66 (3) (2014) 547–556.
[103] N. Apergis, J.E. Payne, K. Menyah, Y. Wolde-Rufael, On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth ☆, Ecol. Econ. 69 (11) (2010) 2255–2260.
[104] J. Baek, D. Pride, On the income–nuclear energy–CO_2 emissions nexus revisited, Energy Econ. 43 (2) (2014) 6–10.
[105] J.P.C. Bento, V. Moutinho, CO_2 emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy, Renew. Sustain. Energy Rev. 55 (March) (2016) 142–155.
[106] N. Apergis, J.E. Payne, Renewable and non-renewable electricity consumption-growth nexus: evidence from emerging market economies, Appl. Energy 88 (12) (2011) 5226–5230.
[107] N.B. Behmiri, J.R. Pires Manso, Does Portuguese economy support crude oil conservation hypothesis? Energy Pol. 45 (2012) 628–634.